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TRACK AND SUPPORT REHABILITATION 1975 ON BLACK MESA & LAKE POWELL RAILROAD

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ABSTRACT

Presented are the initial support and tie foundation problems of a railroad track built in 1974 to carried axle loads 21 % greater than presently (1998) permitted under interchange laws. Described are the concerns related to and affecting the final rehabilitation that resulted in a final satisfactory performance. Of particular interest to the foundation engineer is the ballast, the tie and to a lesser extent the rail behaviour. The use of cobble sized river gravel in the rehabilitation permitted the establishment of guidelines for future use of this source of material where suitable quarried rock is not available. The satisfactory performance after rehabilitation has proven that the design concepts involving 40 ton (36 tonne) axle loads operating on 119 lb/yd (60 kg/m) continuously welded rail, concrete ties and ballast from a river aggregate were achievable.

KEYWORDS

Railway track, Concrete ties, Ballast aggregate, Aggregate, Crushed face, Rail, 40 ton (36 tonne) axle loads.

INTRODUCTION AND BACKGROUND

The Black Mesa and Lake Powell Railroad was opened for traffic in January 1974. Its length is 78 rail miles (125 km) stretching between the Black Mesa coal mine to the Navajo Generating Station on the shores of Lake Powell near Page, Northern Arizona. The route contains a 2.5 degree maximum rate of curvature (except for the turning circles at each end), and a 0.4 % maximum compensated ruling grade with fully loaded train and 2.4 % for the unloaded train. The railroad's design incorporated many concepts of the then most advanced technology of high capacity railroading. The operation is totally automated. The hauling power consists of three electric 50,000 volt locomotives coupled in series. They were the first 50,000 volt locomotives in the world ever placed into service. Each locomotive is rated at 6,000 horsepower (4.472 mega watt). They haul 80 freight cars, each weighing 160 ton (145 tonne) fully loaded. The loaded freight cars resulted in static wheel loads 21 % greater than presently (1998) permitted for North American interchange traffic. At the time the freight cars were the heaviest axle loads ever used in North America for railroad transportation. The design operating speed for the train was a constant 55 mph (88 kph).

The roadbed, which was well drained and mainly composed of medium to fine sand, was scarified to a depth of 6 inches (150 mm). Water was then added and mixed into the scarified soil and then compacted to a minimum 90% modified Proctor density as detailed by American Society for Testing Materials D-1557 (ASTM D-1557). A 12 inch (305 mm) thickness of broadly graded granular sub-ballast (ASTM D-2940) was then compacted to a minimum 95 % modified Proctor density. The track was constructed on the sub-ballast. It consists of Gerwick RT-7 pre-stressed concrete ties and 119 lb/yd (60 kg/m) continuously welded rail. A 10 inch (250 mm) depth of top ballast was then placed, sledded and tamp compacted in several lifts under the base of the track ties followed by placement of top ballast in the cribs. The top ballast is graded 1.5/0.75 inch (38/19 mm) or 90-100 % passing a 1.5 inch (38 mm) sieve, 0-15 % passing a 0.75 inch (19 mm) sieve. This is typical of ASTM D-488 No. 4 grading limits or Manual for Railway Engineering, American Railway Engineering Association (AREA), No. 4 ballast grading limits (see chapter 1, Vol. 1). The ballast was manufactured from coarse river gravel.

The reality of totally new equipment operating in all phases with automatic control was short lived. The problems associated with the operations were resolved quickly by the operational personnel. The problems associated with the track structure and its support were another matter. The main problems were:- (a) A strike at the mine had depleted the 3 month coal stock pile at the power station's coal storage yard. (b) The instability of the track structure did not permit the power station to operate totally from coal. (c) While the power station was capable of operating on either coal or oil, the additional cost of a total operation on oil rather that coal was (at that time) U.S. $1,500,000 per day.

TRACK INSPECTION

Track inspection involved examination of 20 ties at each mile post plus all track on curves of 30 minutes and greater and identified four topics, related to the track, for further consideration. These were:- (a) Rail structural capacity and rail head wear on all curves. The condition of the rail head is illustrated in Fig. 1. (b) Tie clip/tie shoulder and tie pad performance. The condition of the tie clip/rail seat and soft pads are illustrated in Fig. 2. (c) Concrete tie versus wood tie performance. (d) Ballast particle surface shape and origin source. There were no noted problems related to drainage or the subgrade.

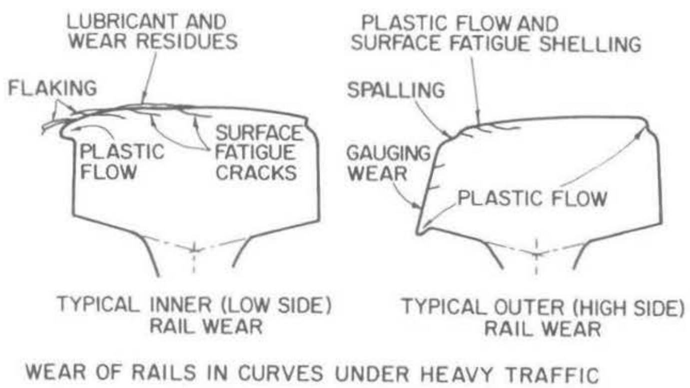

Fig. 1. Typical form of rail head damage.

Fig. 2. Typical tie seat damage.

RAIL EVALUATION

Track deformation measurements established the track modulus for the Black Mesa and Lake Powell Railroad as 13.3 ksi (91.6 MPa). Using this value and the Manual for Railway Engineering (AREA) recommended speed impact factor the calculated maximum bending rail stress was determined to be 16.5 ksi (114 MPa) which compares favourably with 25.0 ksi (172 MPa) permissible for welded rail. The wheel/rail contact pressure was calculated to be 1,053 lb/in (191 kg/cm) of wheel diameter which is only slightly greater than the 1,000 lb/in recommended by the Manual for Railway Engineering (AREA) and is independent of rail weight. Based on these calculated a systematic rail grinding program was recommended to prevent any problems of rail overflow, head checks and corrugations. Estimations suggested grinding all curves every 2.5 years and all tangent (straight) track every five years. This was preferred to changing to heavier rail. No immediate grinding was undertaken which fortunately allowed a study of rail wear damage as related to train speed on curved track. All curves were initial cant elevated for a constant train speed of 55 mph (88 km/h). Unfortunately the loaded train was unable to negotiate all the track curves at the design speed and this was noted one year later (1976) to be causing considerable rail damage. After evaluating rail damage and train speed on all curves the track was re-elevated to give correct balanced cant for each individual curve.

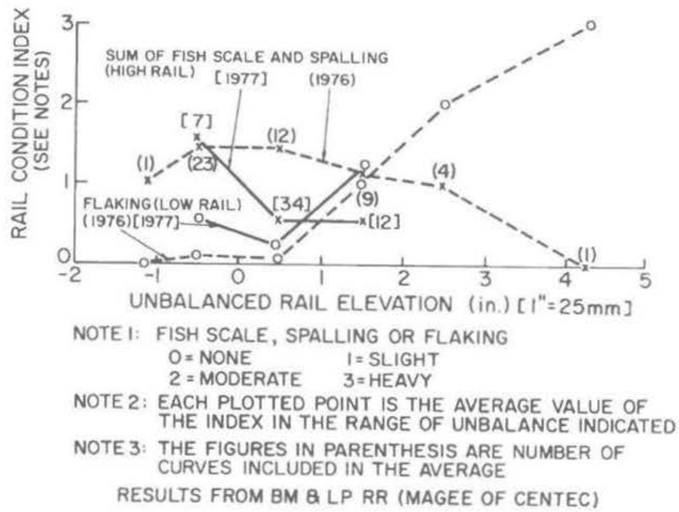

Fig. 3. Results of observations of rail condition in curves on the Black Mesa and Lake Powell railroad.

The rail head damaged conditions observed on the low and high rail head in curves prior to and after re-elevation to balanced speed are illustrate by the plots in Figure 1. The observed conditions were subjectively classified into four degrees of severity: 0=none or no damage; 1=slight damage; 2=moderate damage; and 3=heavy damage. The values plotted are the average from the number of curves noted in parenthesis on the plot. The dashed lines represent the conditions in 1976, and the solid lines the conditions in 1977. Figure 1 clearly shows the improvement achieved from one year of heavy axle loads in the condition of the rail on the rail head by comparison with the observations taken in 1976, just prior to cant balance. Note that over the period of observation no grinding or other rail surface improvement was undertaken.

The improvement demonstrates the importance of ensuring that the foundation ballast is elevated at correct balanced speed cant through all curves. Similarly the forces (particularly lateral forces) transmitted to the track and its support would be improved.

TIE CLIP AND PAD EVALUATION

Clip and bolt failure was so severe that maintenance personnel were replacing the design mild steel bolts with high strength bolts prior to the arrival of the inspection team. Fortunately the cast-in-concrete inserts for the bolts were high strength stainless steel. Thus a recommendation for a complete change-out of the clips and bolts to "Hi-Strength" (ASTM A-325 steel) cadmium-plated (for corrosion prevention) clips and bolts was immediately adopted. A further problem was the design soft rail/tie elastomeric pads. As the bolts were changed these soft pads were changed to hard polyethylene. In addition, the new bolts were dipped into oxide-preventive grease to seal the stainless steel threads from moisture. The bolt clips were tightened to a torque of 150 lb-ft (200 kN-m) and checked on a systematic basis.

CONCRETE TIE EVALUATION

There was obvious major tie holding instability on the curves. Calculations showed that the concrete tie track with its 26.5 inch (0.669 m) spacing would have a 10 % stronger lateral strength than wood ties at 19.5 inch (0.492 m) spacing. Considering only the holding capacity of the ballast there would be a disadvantage to change to wood tie track, however this neglected the consideration of rail/tie bolt failures. The railroad commenced a replacement of the concrete ties by wood ties on all curves without replacement of the ballast despite a warning that changing the ties without more stable ballast (through more crushed faces) could result in a derailment. Indeed such a derailment did occur on the new wood tie (curved) track. Unfortunately no cause was investigated due to the urgency of moving coal, however the derailment strengthened the urgency for a new ballast on any curve with wood tie track (as discussed later). The original soft pads allowed excessive rail movement and resulted in sever shoulder spalling. As given in Table 1 about 18,000 spalled shoulders existed in the curved track. The percentage of spalls increased as the curvature increased. Another 18,900 spalled shoulders existed in tangent (straight) track. Center bound ties (cracked) tended to increased as the curvature increased. These spalls were repaired using epoxy mortar and after a cure time of 24 hours withstood a lateral shoulder force equal to that of new ties which was about 25 kip (111 kN) force per shoulder. Since all concrete ties were being replaced in curves the repaired ties were only used in tangent (straight) track, including a new additional passing track. The repaired ties have performed satisfactory for over 20 years.

Tie/ballast contact pressures were calculated on the AREA Manual assumption that the ballast contact pressure was uniform, resulting in calculated tie/ballast contact pressure (allowing for recommended impact) of 72 psi (496 kPa) which is less than the permissible maximum contact pressure of 85 psi (586 kPa). Similarly the calculated maximum rail seat bending moment was 228 kip-in (25 kN-m), which was greater than the recommended design value of 165 kip-in (18 kN-m) but less than the lowest tested rail seat bending moment; measured at first crack as 245 kip-in (27 kN-m). None of the removed concrete ties showed signs of rail seat cracks and none were reported to have occurred. The concrete ties were assessed as satisfactory, however 5 % were centerbound cracked. Since there was no obvious increase in the centerbound cracks with increased rate of curvature (Table 1) these cracks could have been due to construction forces. Furthermore, the cracks did not extend more than 1.5 inches (38 mm) below the surface and were considered superficial. An application of a sealer (Fel Pro) was applied to prevent moisture penetration and to permit identification of new cracks.

TABLE 1. Tie Data to May 1975 for Black Mesa and Lake Powell Railroad.

Curve degree-minutes	Number of ties inspected	Percent center cracked	Percent spall at rail seat	Comments
0-00	980	4.8	15.9	Tangent
0-30	140	15.7	15.7	
1-00	240	6.3	22.1	
1-30	200	9.0	19.0	
2-00	140	1.4	27.9	
2-30	2,677	5.1	28.2	
7-30	320	2.5	19.4	Turning

BALLAST EVALUATION

Because no local source of suitable quarry rock was available the supplied ballast was graded as ASTM D-488 (size from 38 mm down to 19 mm) and required 95 % by particle count of particles with at least one crushed face. The ballast source was rounded coarse sized river gravel obtained from the Colorado river near Page. The contractor had available a cone crusher capable for crushing a 3 inch (75 mm) to 4 inch (100 mm) maximum sized particle. To obtain a suitable aggregate source the contractor passed the river material through a 3 inch (75 mm) grizzle sieve (steel bars at 3 inch or 75 mm spacing) on to a 1.5 inch (38 mm) grizzle sieve. This sorted material was then used as the ballast aggregate source. All quality control data reviewed had an uncrushed particle count of between 4% to 6%. Ballast samples taken from track confirmed the quality control information to be correct, however a 5% uncrushed particle count resulted in a 15 % uncrushed sample by weight. Such a high level of uncrushed material would result in poor tie/ballast holding ability and this appeared to have been verified by the already mentioned derailment that had occurred when the concrete ties on the curves were being replaced by wood ties.

The existing ballast tested: Los Angeles Abrasion (ASTM C-545 grading 3) = 19.7 %; Mill Abrasion (CP ballast specification 1985) = 1.4 %; Magnesium Sulphate Soundness (ASTM C-88) = 0.4 %; Rodded Dry Density (ASTM C-29) = 98 lb/cu ft (1603 kg/cubic m). A petrographic analysis involving orthogonal thin sections indicated most minerals present had Moh's hardness values greater than 5.5. Clearly this was a very good source material if it could be suitably crushed. A stock pile of the material wasted by the contractor that had been retained on the 3 inch (75mm) grizzly was obtained from the local source site. Based on the crushing of these cobble sized particles a specification for new ballast to re-ballasting all curves to a depth of 4 inches (100 mm) was established (A similar, slightly different and more demanding wording, is available to test the shape of crushed quarried rock in CP Rail's 1984 ballast specification). This specification required:

(a) 99 % or more, by weight, of particles to have 2 or more acceptable crushed faces, and

(b) 75 % or more of particles, by weight, to have 3 or more acceptable crushed faces.

(c) An acceptable crushed face is a freshly exposed plane having a minimum dimension at least one-quarter of the maximum particle dimension. The minimum dimension is the minimum distance between two separate parallel lines, neither of which bisect the crushed face, but both of which touch its outer perimeter. The included angle formed by the intersection of average planes of adjoining fractured faces must be less than 135 degrees for each face to be considered as separate acceptable crushed faces.

Quality control is simply done with a calliper and a tool consisting of two welded straight bars having an angle of 135 degrees between straight edges. Actual data from use of the above requirement have consistently achieved 80 % to 85 % of particles with 3 acceptable crushed faces. Performance of the newly crushed material has been excellent.

POST REHABILITATION PERFORMANCE

Although today (1998) two trains operate on the railroad and axle loads have been reduced to interchange limits (33 ton or 324 kN), a single train with design axle loads was used for some time after rehabilitation. Figure 1 was obtained for the design axle loads. Indeed, prior to the delivery of the second train, records show that axle loads occasionally exceeded design values by as much as 5 % (due to overloading). It is clearly evident that the designers concepts are and were possible. The performance after rehabilitation has proven this. It is unfortunate that the initial problems at the Black Mesa and Lake Powell railroad were not better understood. Drawing conclusions such as "there is a limit to the size of wheel loads and 125-ton four-axle cars have exceeded that limit" (Sunnygard, 1977) based on rail wear on curves from the Black Mesa and Lake Powell railroad that were incorrectly balanced for cant are misleading. Indeed evidence today (1998) shows that a number of railroads are opting to use 40 ton (392 kN) axle loads without undue consequences. Only when a full understanding is reached will correct evaluations be possible. Rail wear behaviour is an extremely complex problem in which steel, under North American freight wheel loads, will be loaded above the elastic limit unless hardened. The topic needs much research and is beyond the scope of the work reported herein.

CONCLUSION

The rehabilitation of the Black Mesa and Lake Powell Railroad's track and support has clearly demonstrated that the design concepts involving 40 ton (36 tonne) axle loads operating on 119 lb/yd (60 kg/m) continuously welded rail, concrete ties and ballast from a river aggregate were possible. The improvements and modifications included: (a) improved rail head wear by canting curves to balanced speed for the loaded train, and by future grinding, (b) improved tie clip and pad performance by complete replacement of mild steel bolts by high strength and soft pads by hard , (c) improved concrete tie performance by repair of spalled shoulders, use of uniform bolt torque and improved tie clip and pads, and (d) improved holding capacity of the ballast by the quality control of the ballast particle surface and shape obtaioned from the original ballast source through the use of cobble size particles. The use of cobble sized river gravel permitted the establishment of guidelines for future use of this source of material where suitable rock is not available. The guidelines would require:

(a) 99 % or more of particles, by weight, to have 2 or more acceptable crushed faces, and

(b) 75 % or more of particles, by weight, to have 3 or more acceptable crushed faces.

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